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An X-Ray Micro Computed-Tomography System for 3-Dimensional Microstructure Characterization of Multifunctional Composites

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13. ABSTRACT *(Maximum 200 Words)*
An X-ray micro computed-tomography system (Skyscan 1172) has been installed and operated successfully at UCLA. The system is used for non-destructive characterization of 3-D microstructures of multifunctional composites for advanced aerospace systems and is found to be a very powerful instrument for various composites. The composites and devices under study include graphite nanoplatelet (GNP) and carbon nanotube (CNT) composites, energy harvesting/storage composites, ink jet printed electrodes, and thin film batteries. The tomographic images can show agglomeration of nanoparticles such as GNPs and CNTs as well as microvoids. They can also show internal damages in thin-film solar cells and batteries.

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An X-Ray Micro Computed-Tomography System for 3-Dimensional Microstructure Characterization of Multifunctional Composites

A Skyscan 1172 scanning X-ray micro computed-tomography system (Skyscan 1172) including a mechanical loading stage, a cooling stage and an X/Y stage was purchased and installed at UCLA to carry out non-destructive characterization of multifunctional composites, Fig. 1. The specifications of the machine are provided in Table 1.

(a)

(b)

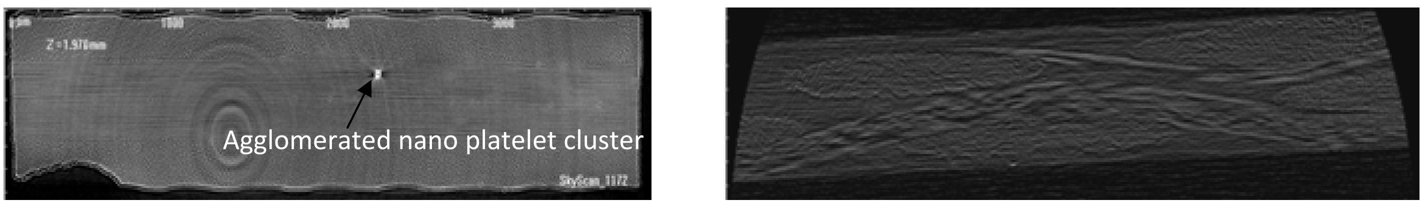
Fig. 1. The installed Skyscan 1172 scanning X-ray micro computed-tomography system: (a) overall system; (b) specimen holder inside the chamber

Table 1. Specifications of the X-ray micro tomography system

Item	Quantity	Model	Description
1	1	Skyscan 1172 100kV 2k x 4k	X-ray micro-CT systems with detail detectability <2 μm and spatial detectability <5 μm. Max. object size 35 mm.
2	1	Reconstruction Cluster	Networked cluster of computers including network software for reconstruction.
3	1	Mechanical Loading Stage	Tension and compression
4	1	Cooling Stage	45^{o} C delta, 0.5^{o} C accuracy
5	1	X/Y Stage	Precise specimen alignment
			Total
			Educational Discount 5%
			Equipment Price
			CA Sales Tax 8.25%
			Total System Cost

Multifunctional composites and devices whose 3-D microstructures are characterized on the machine include graphite nanoplatelets (GNP) and carbon nanotube (CNT) composites, multifunctional energy harvesting/storage composites, a chemically bonded phosphate ceramic with microvascular network, inkjet-printed electrodes, and thin-film solar cells and batteries. The equipment is specifically being used to support a number of AFOSR projects.

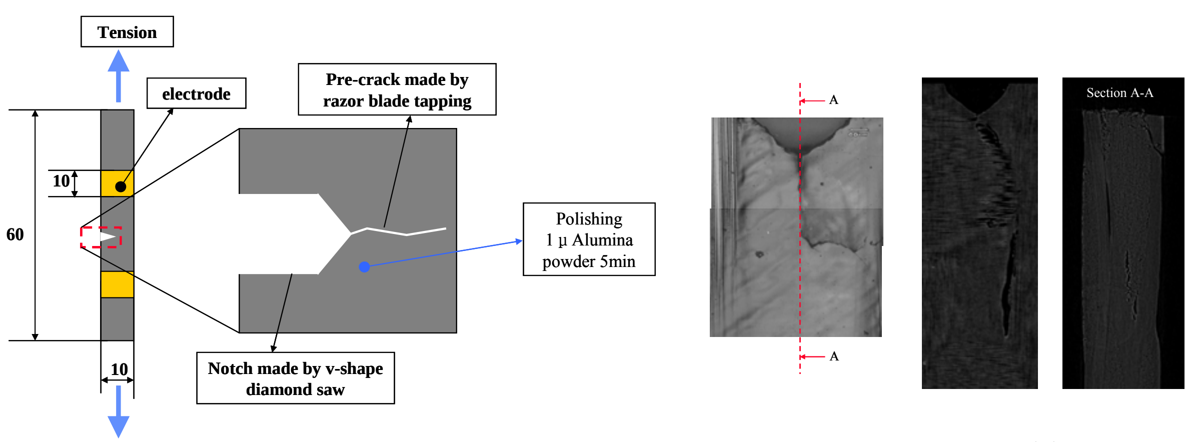
The main goal of one project is to improve the structural integrity of polymer composites by incorporating nanoreinforcements such as GNPs and CNTs. The equipment is ideally suited for investigating the particle dispersion as it does not require any special specimen preparation. Figure 2 shows 2-D X-ray images of a GNP/epoxy composite and a carbon fiber composite with CNTs. Although the smaller dimensions of these nanoparticles are below the maximum detectable limit (2 μm) of the equipment, agglomerated nanoplatelet clusters could be detected, Fig. 2 (a).



(a) (b)

Fig. 2. 2-D X-ray images of nanocomposite: (a) GNP/epoxy; (b) carbon fiber/epoxy composite with CNTs.

The goal of another project is to develop a self-healing composite by using a thermally mendable polymer in combination with carbon fibers. X-ray tomography scanning was conducted to detect crack propagation and crack healing in the self healing composite. Figure 3 shows an experimental set-up to induce cracking in the matrix and the cross-sectional X-ray images of the specimen. Skyscan 1172 can be used to detect internal cracking without destroying the specimen, which is not possible in any other way. The equipment allows for multiple healing behavior to be studied on the same specimen.



(a) (b) (c)

Fig. 3. Non-destructive damage monitoring of the self healing composite material: (a) experimental setup; (b) optical microscope image; (c) X-ray tomography scanning result.

The load carrying capability of thin-film solar cells and batteries is being studied under another project. As these devices have weaker functional layers sandwiched between tougher packing layers, these functional layers fail first under mechanical loading. Unfortunately, this type of failure cannot easily be detected from outside. Figure 4 shows a composite laminate with a thin-film lithium battery embedded and a thin-film solar cell mounted on its surface. The laminate was loaded in tension to study how much deformation these functional devices can withstand. The X-ray tomography can clearly detect internal damage inside the battery.

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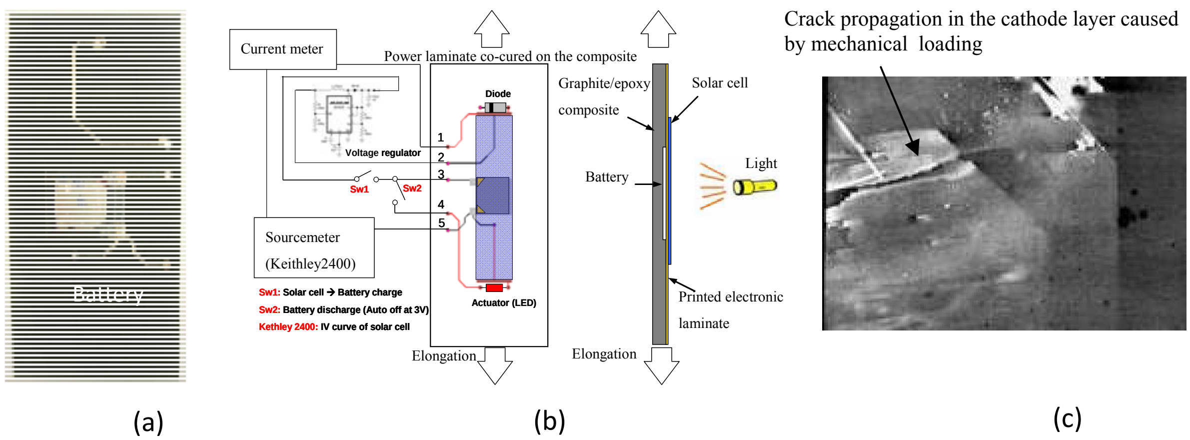

Fig. 4. Failure of a battery embedded in a multifunctional energy storage structure: (a) embedded battery; (b) tensile test of the energy harvesting composite; (c) 2D image of X-ray tomography showing failure modes of the embedded battery

The mechanical reliability and electrical conductivity of printed electrodes critically depend on their microstructure. Figure 5 shows a printed copper electrode with internal voids found through 3D micro tomography. These voids are responsible for the conductivity of the printed copper electrode being lower than that of the bulk copper electrode.

Currently, Skyscan 1172 is being used by many researchers at UCLA. Although other microscopic techniques such as optical and scanning electron microscopy can be used, they are only 2-dimensional and the construction of 3-dimensional microstructure requires sequential sectioning. Furthermore, they are destructive. It is obvious that Skyscan 1172 offers a tremendous advantage by eliminating time-consuming specimen preparation. Needless to say, the instrument will be used to educate not only those students in the PI's group but also in the other departments. By making microstructure characterization easy to do, the instrument will help students appreciate the variety and importance of microstructures in controlling properties of advanced aerospace materials. The result will be the students better educated in advanced aerospace materials for military systems. The instrument is expected to last at least 5 years.

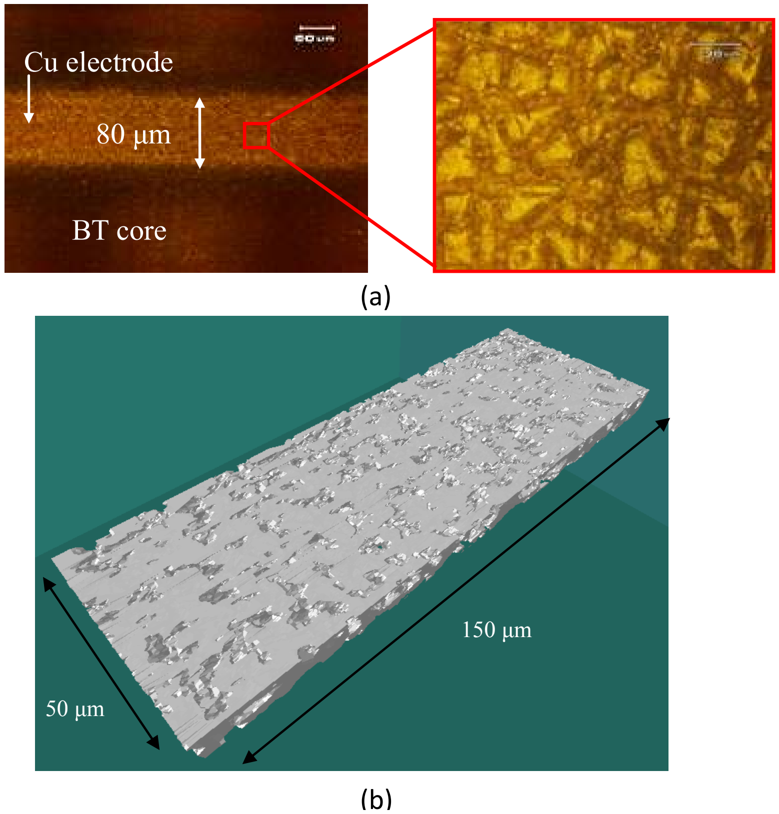

Fig. 5. A printed copper electrode: (a) optical micrograph; (b) 3-D X-ray tomograph